Universidade do Minho
Escola de Ciências

Novel B-decay signatures of light scalars @ high energy facilities

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Where is new physics?

- It has not showed up in “standard candle” final states
- Minimal models are getting strongly constrained

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Look for radically **new** and **unexplored** regions of signal

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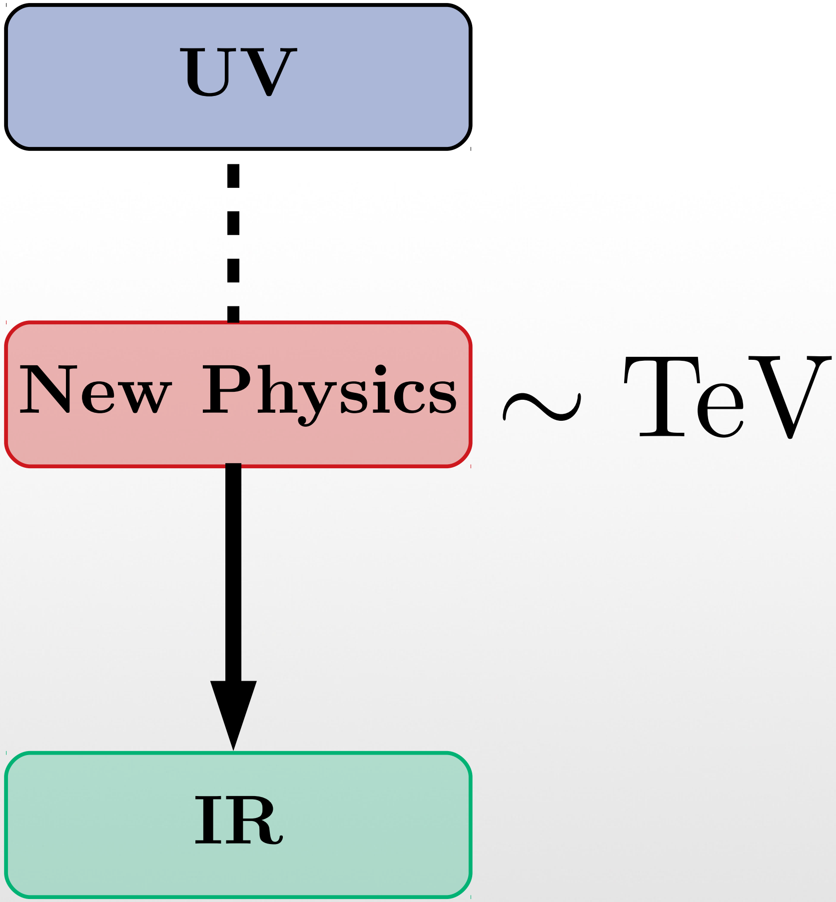
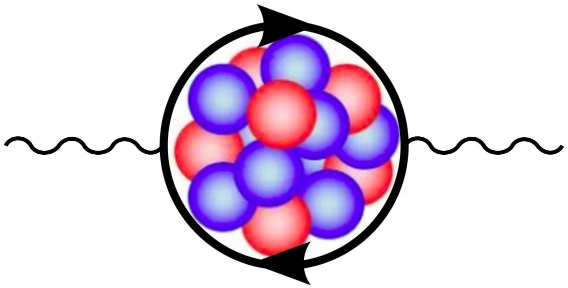
- It has not showed up in “standard candle” final states
- Minimal models are getting strongly constrained

Look for radically **new** and **unexplored** regions of signal in CHMs

The idea of a composite Higgs

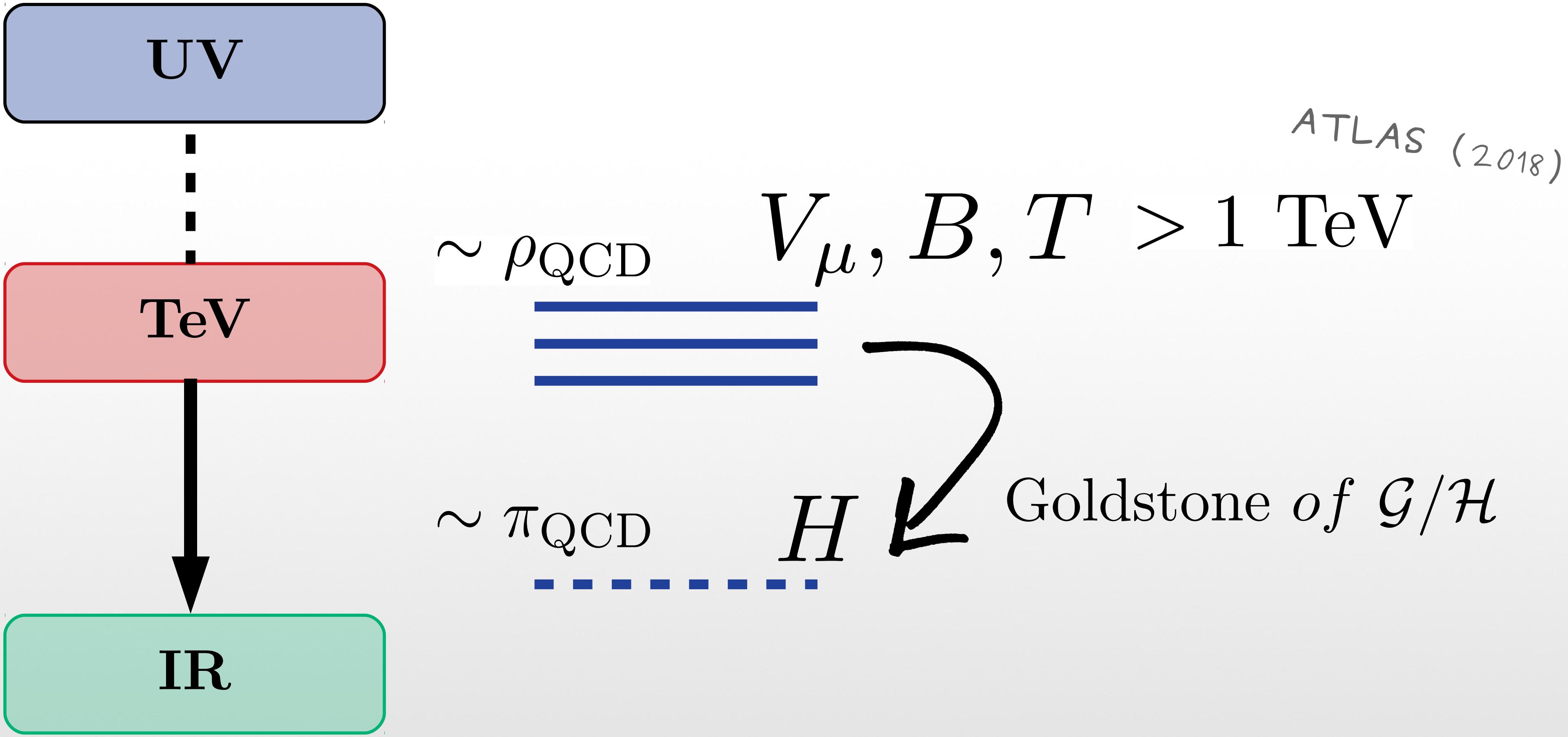


No longer a Higgs scalar at high energies



$$\delta m_H^2 \sim \frac{g^2}{(4\pi^2)} f_*{}^2$$

Minimal phenomenology



UV

TeV

IR

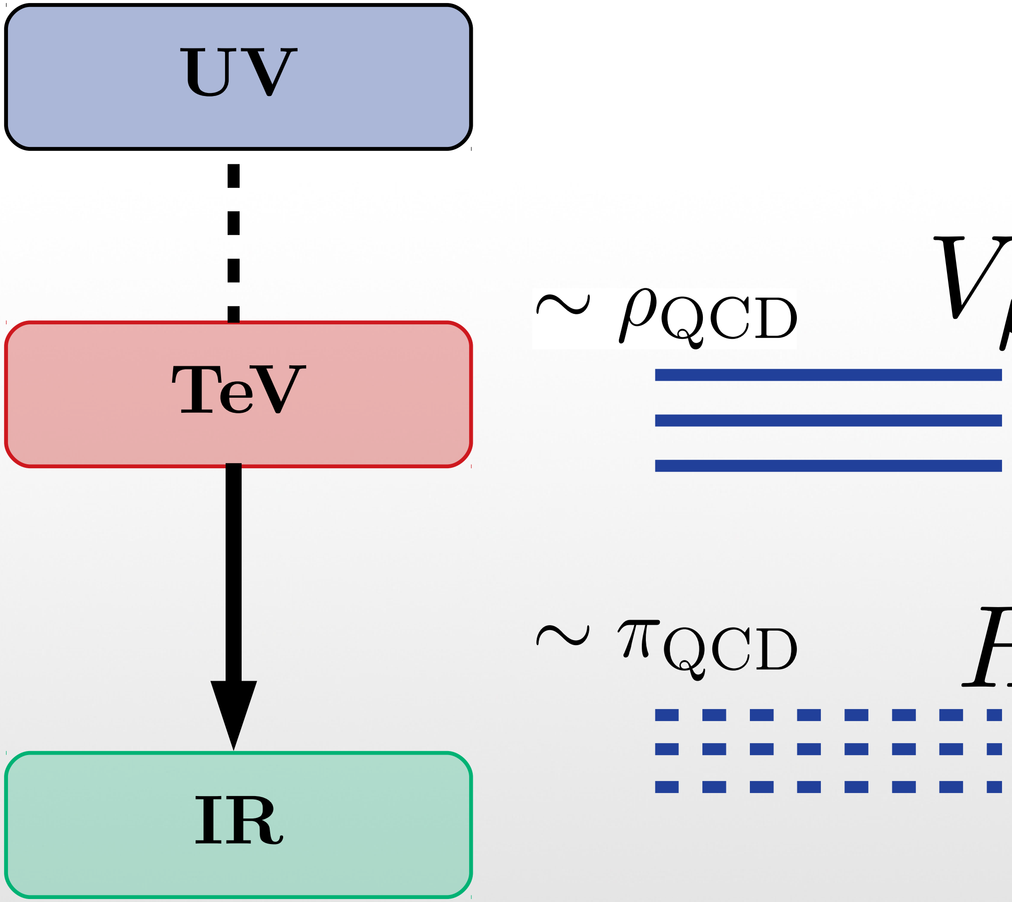
ATLAS (2018)

$\sim \rho_{\mathrm{QCD}}$ $V_\mu, B, T > 1$ TeV

$\sim \pi_{\mathrm{QCD}}$ H

Goldstone of $\mathcal{G}/\mathcal{H}$

Non-minimal phenomenology



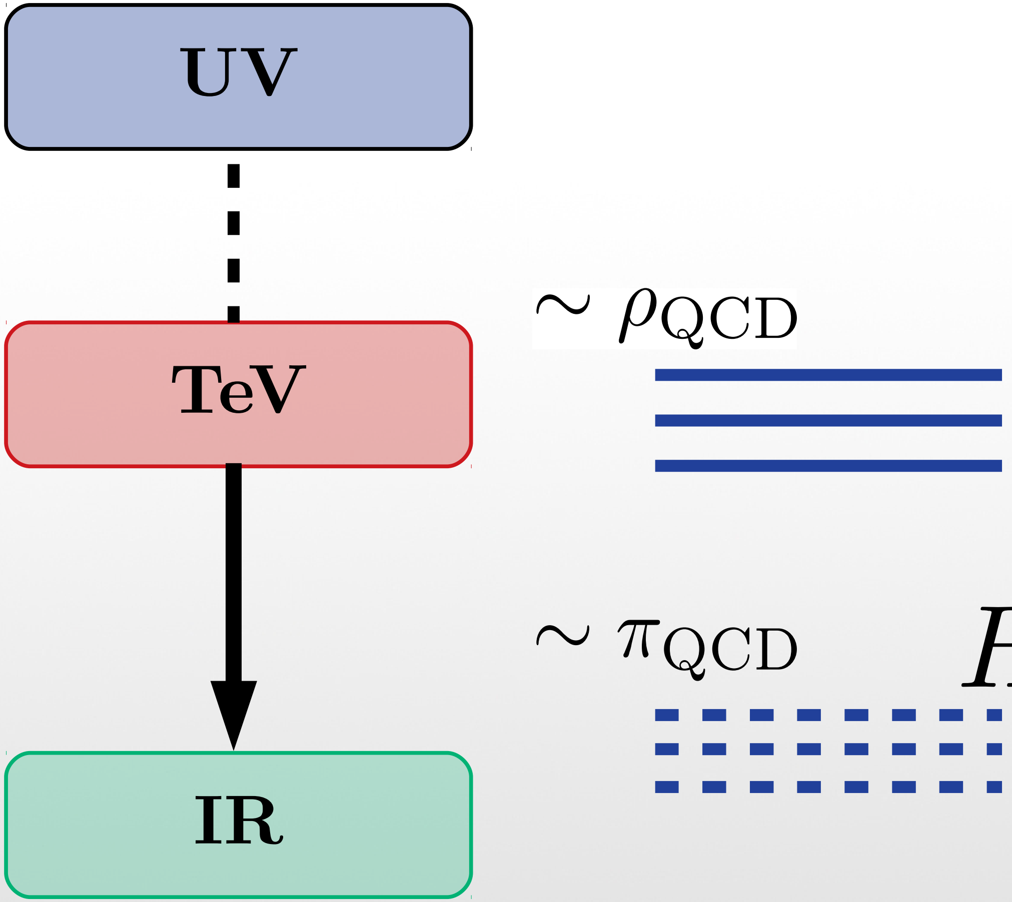
M. Chala (1705.03013)

$\sim \rho_{\mathrm{QCD}}$ $\quad V_\mu, B, T \gtrsim 700$ GeV

$\sim \pi_{\mathrm{QCD}}$ $\quad H,\ S,\ \eta^2,\ \ldots$

UV completions, anomalies, dark matter candidates, explanation for baryogenesis, etc.

Non-minimal phenomenology



$H,\ S,\ \eta^2,\ \ldots$

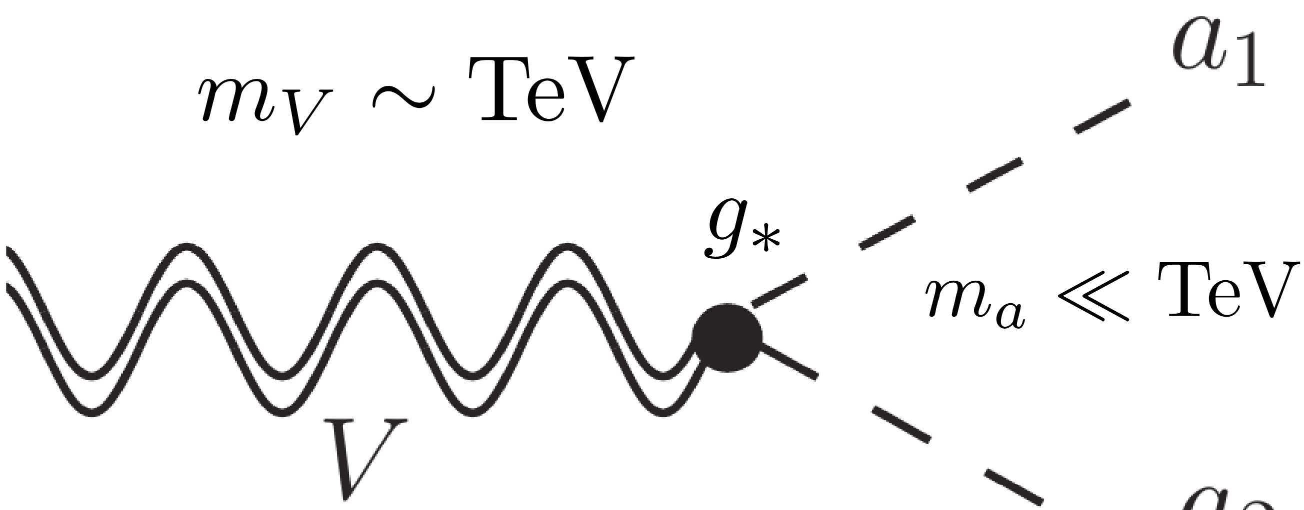
Strategy:

(i) prediction

(ii) signal

(iii) new analysis

B-decay signatures of light scalars



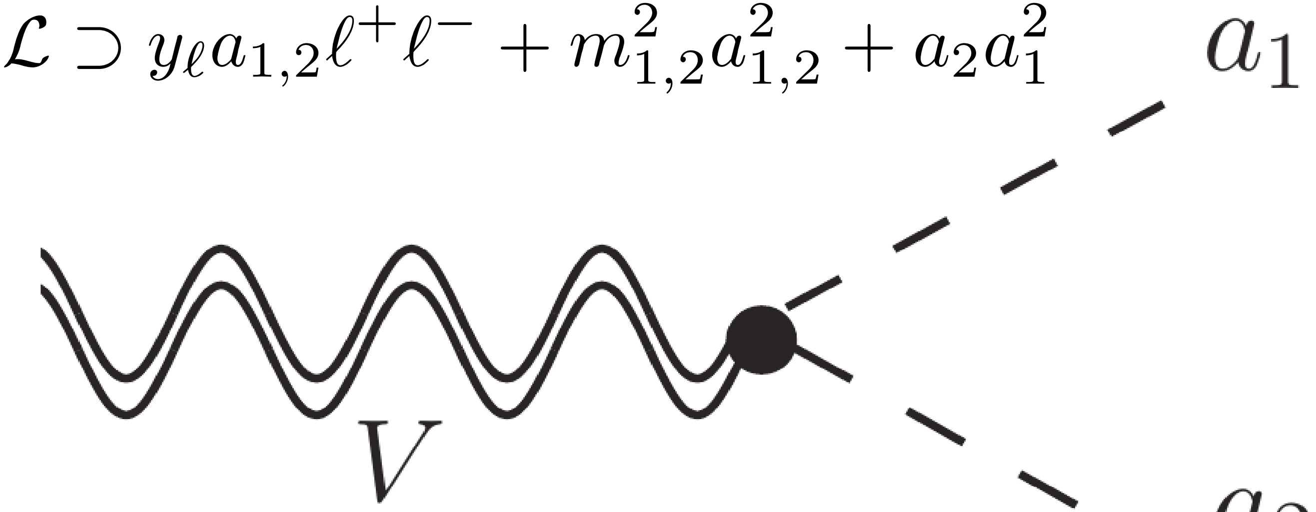
Weaker bounds for composite decays

M.Chala, M. Spannowsky (1803.02364)

B-decay signatures of light scalars

$SO(7)/SO(6)$ model

$$\mathcal{L} \supset y_\ell a_{1,2} \ell^+ \ell^- + m_{1,2}^2 a_{1,2}^2 + a_2 a_1^2$$



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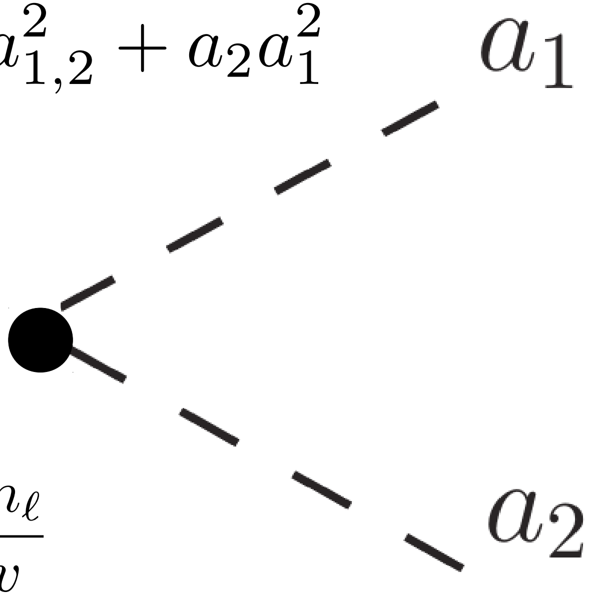


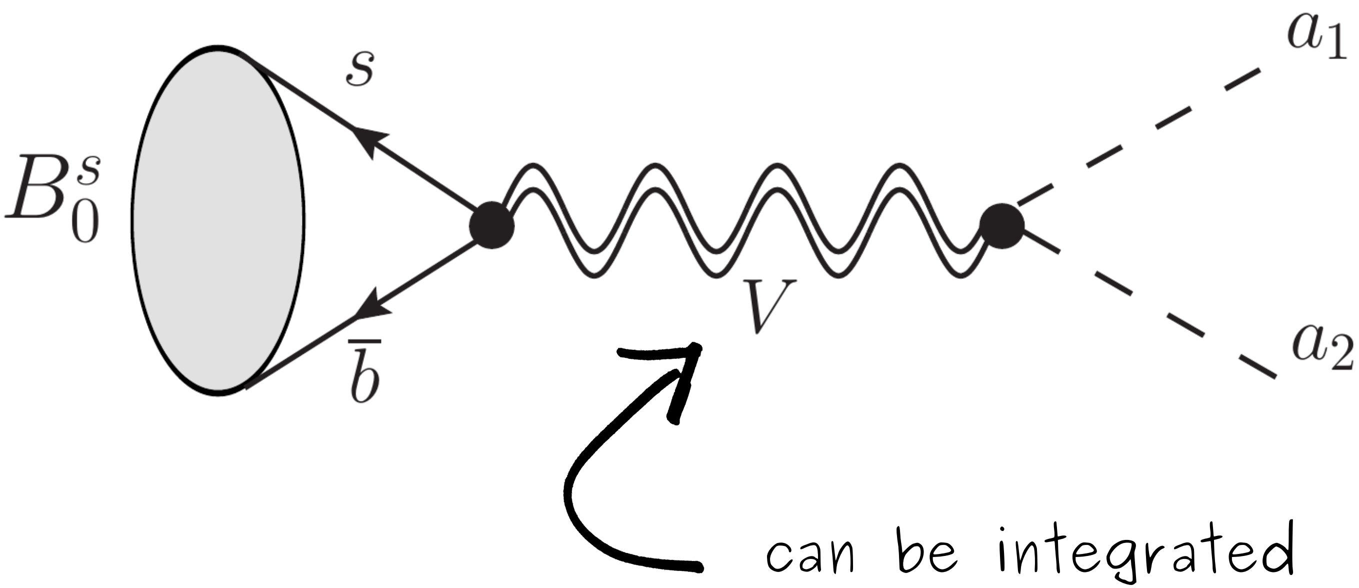
Our assumptions:

(i) a_1 pseudoscalar

(ii) $a_{1,2}$ leptonphilic, $y_\ell \propto \frac{m_\ell}{v}$

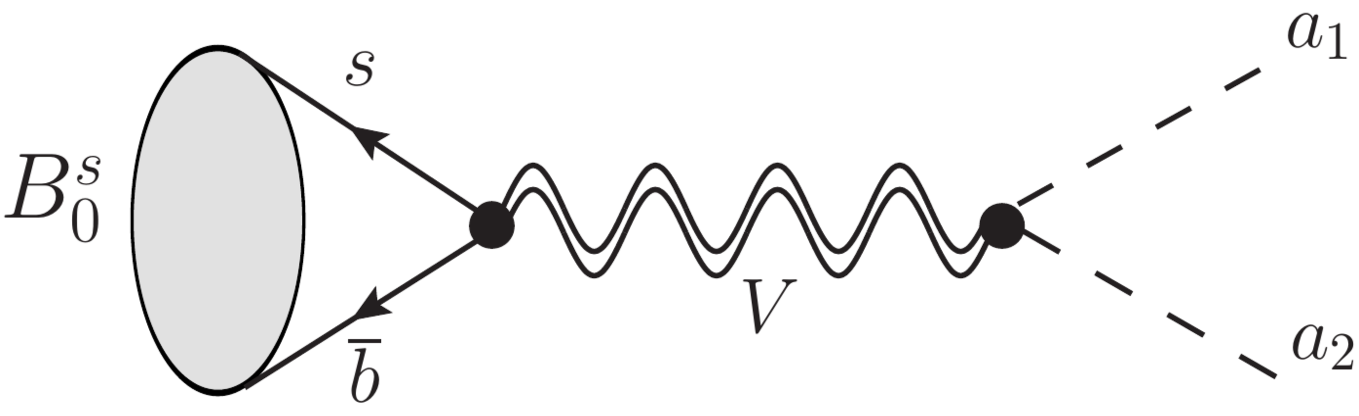
(iii) $m_2 \gtrsim m_1 \sim \mathcal{O}(1)$ GeV

B-decay signatures of light scalars



can be integrated out!

B-decay signatures of light scalars

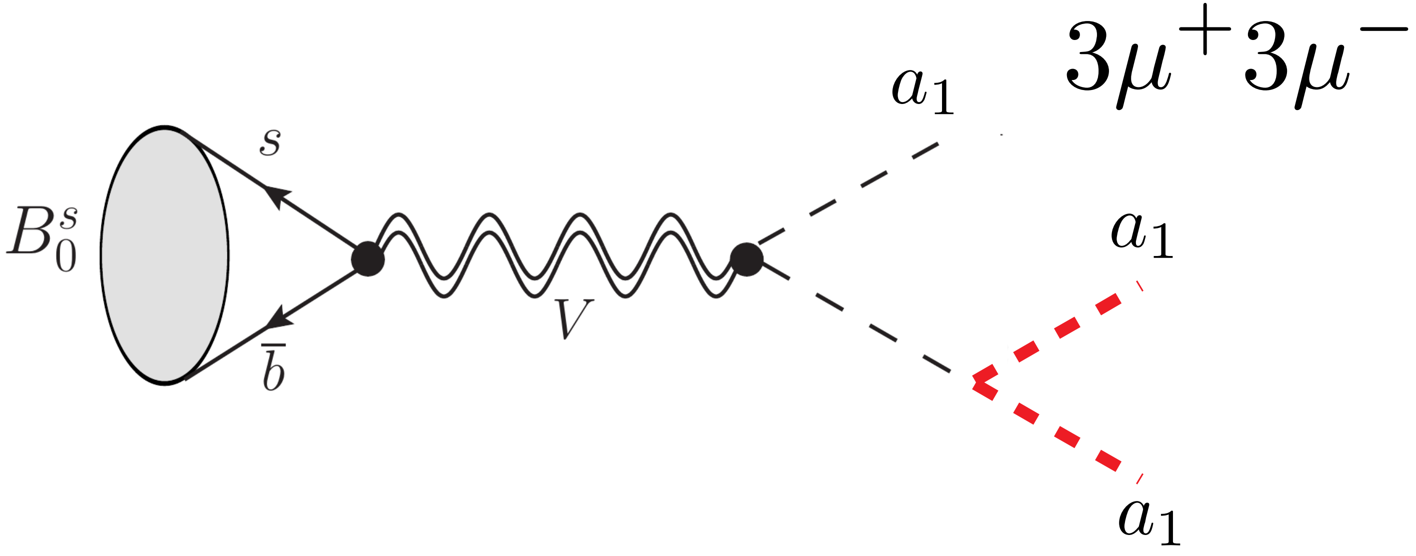


LHCb(2017) @8TeV with 3fb⁻¹ data:

$$\mathcal{B}\left(B_s^0 \to \mu^+\mu^-\mu^+\mu^-\right) < 2.5 \times 10^{-9}$$

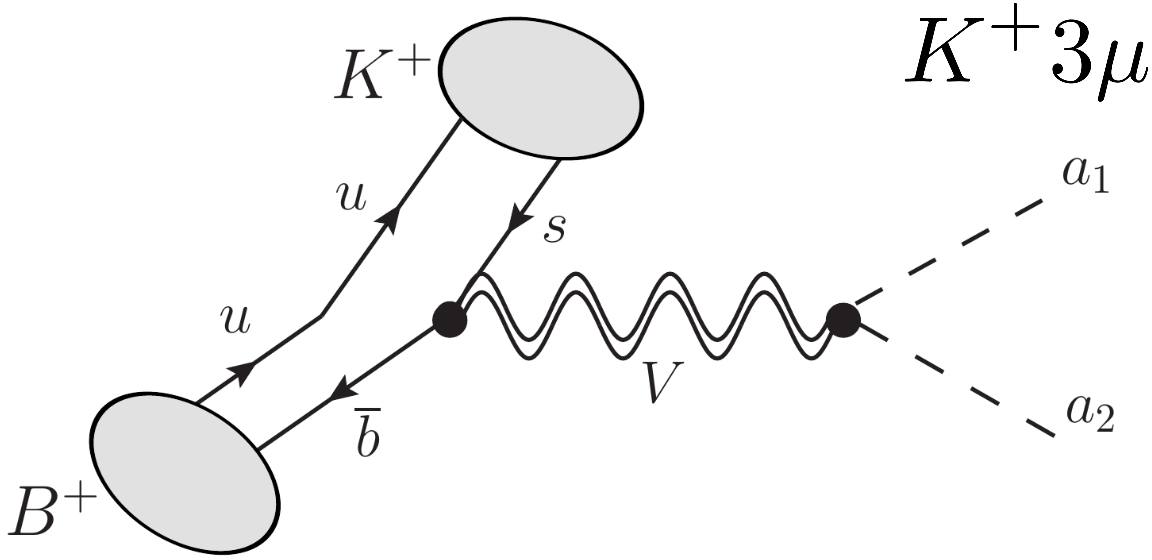
Motivation for alternative decays

#1 $\Gamma\left(a_2 \to \ell^+\ell^-\right) \ll \Gamma\left(a_2 \to a_1 a_1\right)$



Motivation for alternative decays

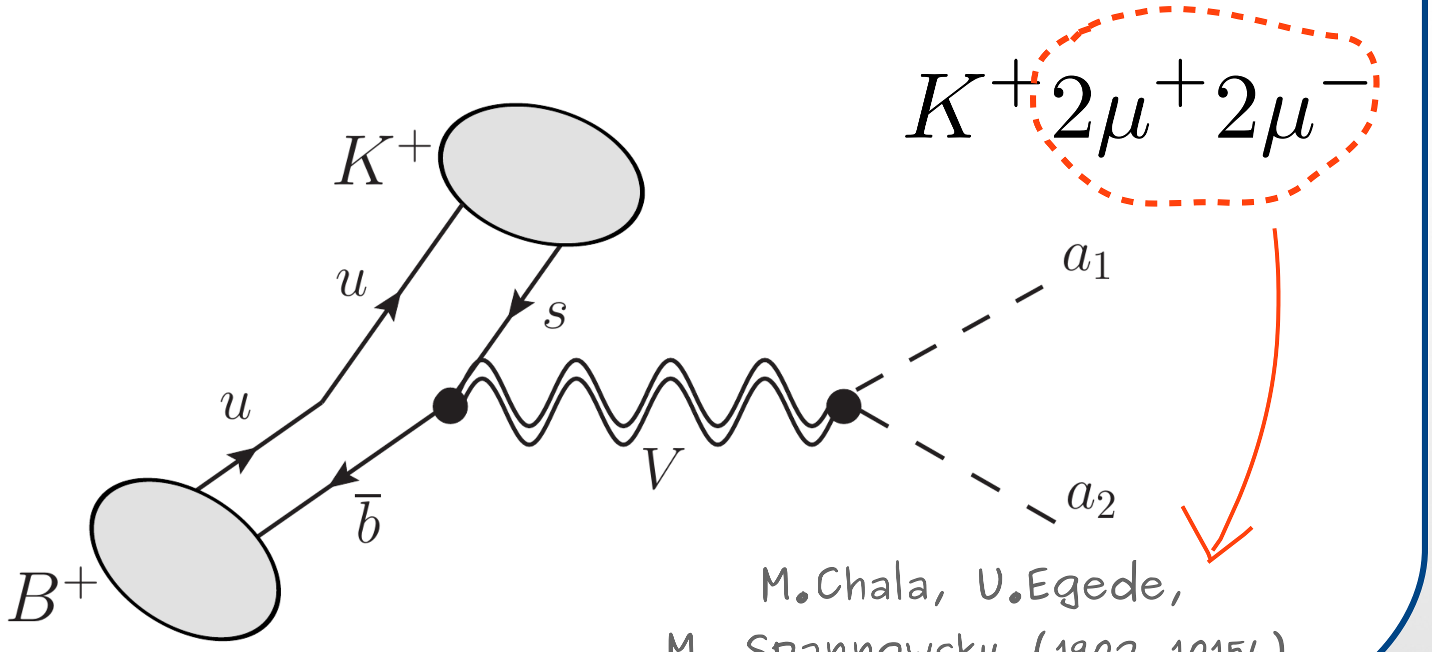
#2 $\Gamma\left(B_s^0 \to a_1 a_2\right) \propto \frac{|m_2^2 - m_1^2|}{m_B}$



$K^+ 3\mu^+ 3\mu^-$

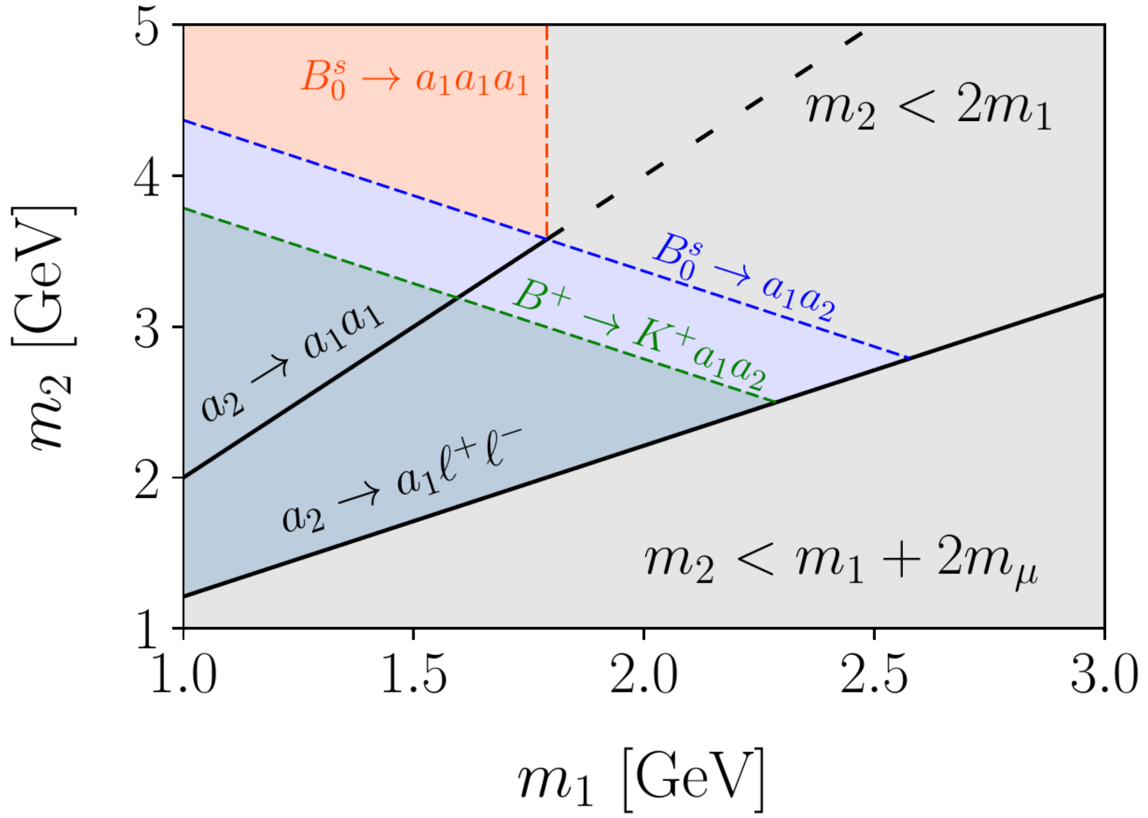
Motivation for alternative decays

#2' This was also not searched:



M.Chala, U.Egede,
M. Spannowsky (1902.10156)

Our parameter space



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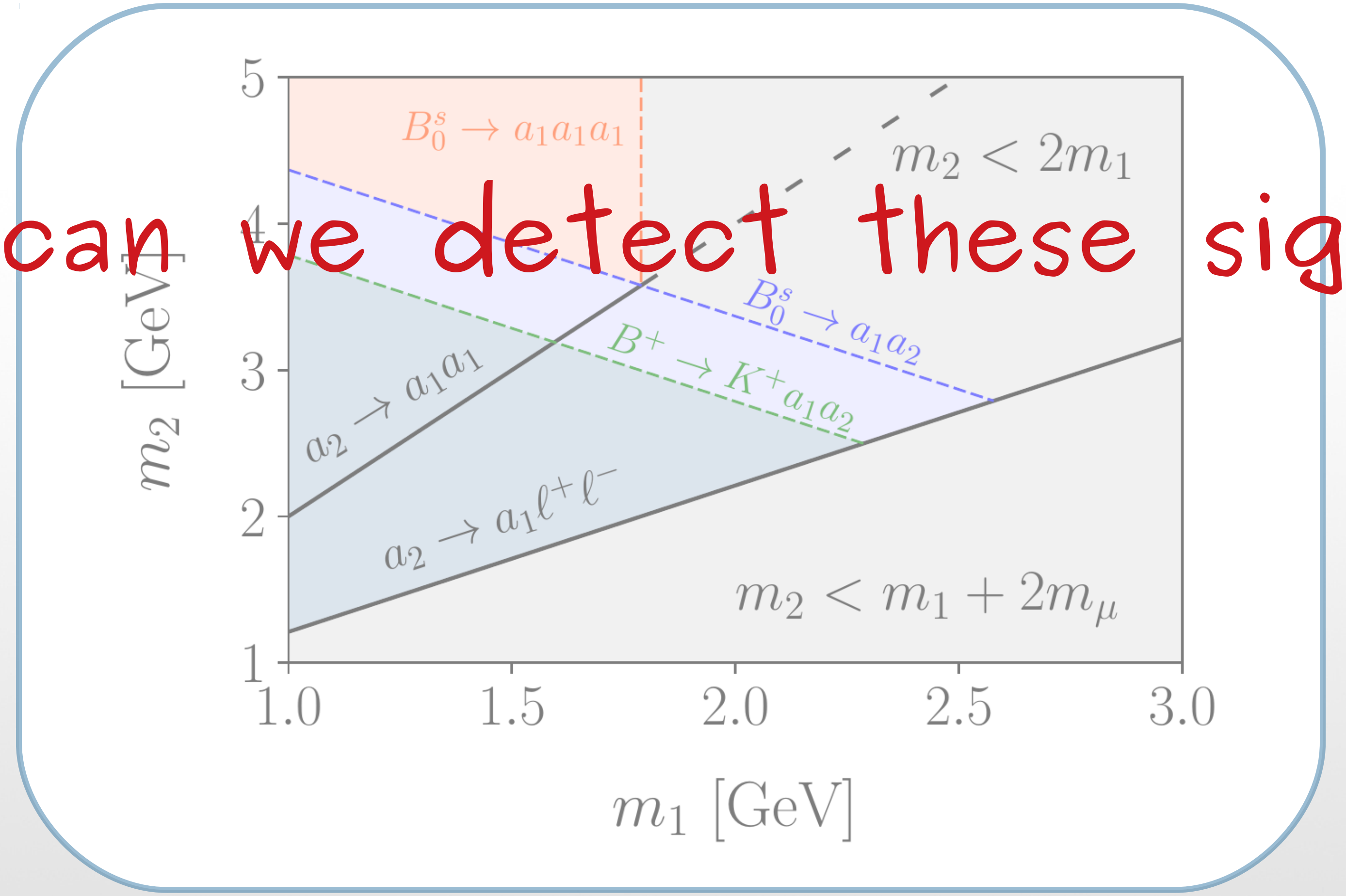
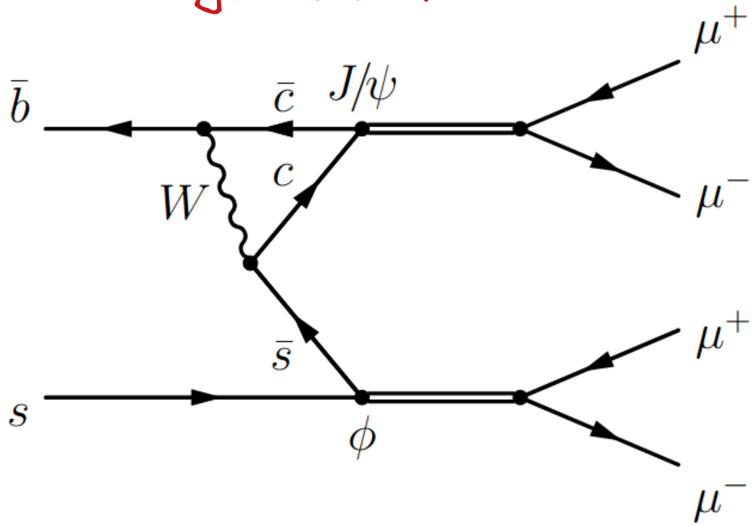


How can we detect these signals?

LHCb analysis to probe these decays

Main background



$\mathcal{B} \sim 10^{-8}$

LHCb analysis to probe these decays

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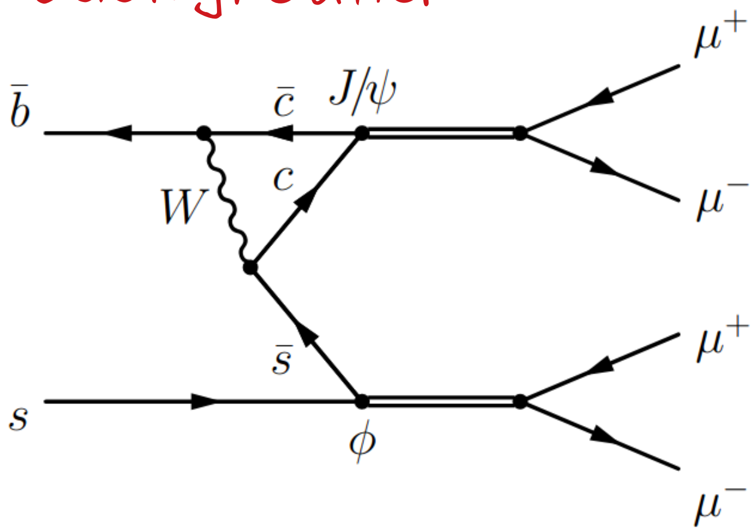
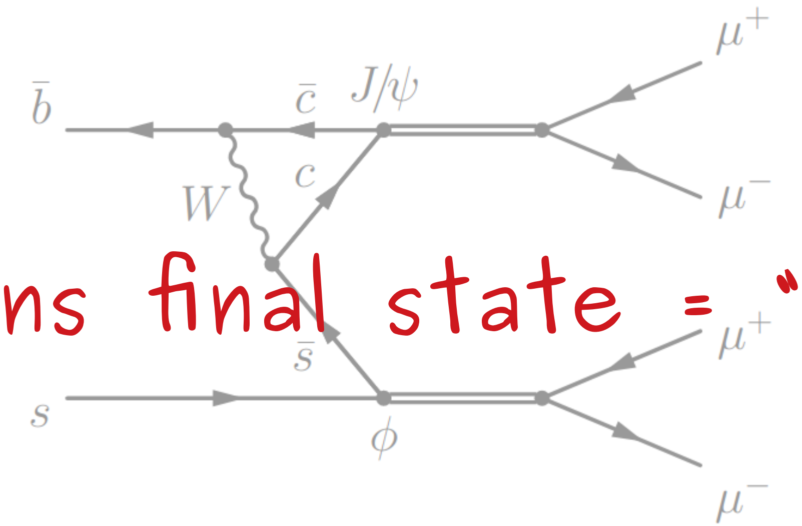


$\mathcal{B} \sim 10^{-8}$

$$m_{\mu^+\mu^-} \notin [0.95, 1.09] \cup [3.0, 3.2]\ \text{GeV}$$

LHCb analysis to probe these decays



6muons final state = “bkg free”

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LHCb analysis to probe these decays

6muons final state = "bkg free"

$$\mathcal{B}_{\max}^{3\mu^+3\mu^-} \simeq \frac{\mathcal{B}_{\max}^{2\mu^+2\mu^-} \times \varepsilon_{2\mu^+2\mu^-}}{1.8 \times \varepsilon_{3\mu^+3\mu^-}} \times \frac{\mathcal{L}}{\mathcal{L}'}$$

$\mathcal{L} = 3 fb^{-1}$

$\mathcal{L}' = 300 fb^{-1}$ @upgradeII

LHCb (2017)

σ_{14}/σ_8

from simulation

LHCb analysis to probe these decays

6muons final state = "bkg free"

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$\mathcal{L} = 3fb^{-1}$

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LHCb (2017)

σ_{14}/σ_{8}

from simulation

Pythia Mg5 Fastjet

Generate $B\to(M)aa$, $a\to\mu^+\mu^-$; boost the muons to B−frame

Particle reconstruction @ LHCb

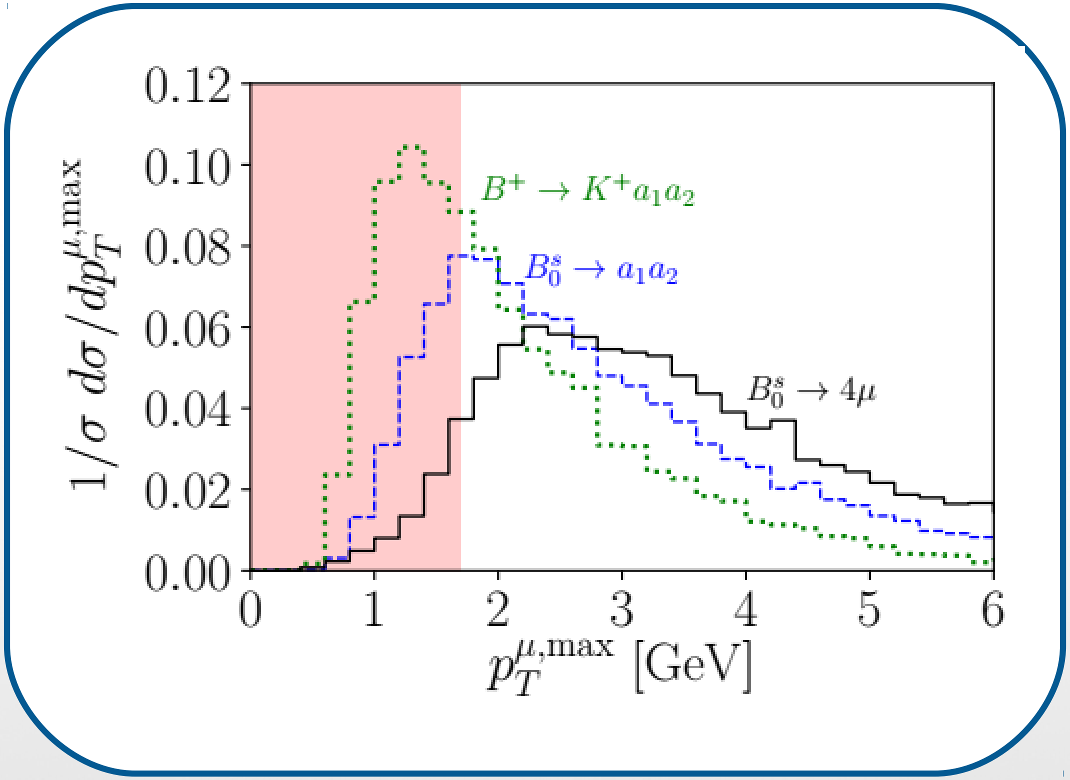
Basic cuts

$p_T > 0.5$ GeV

$2.5 < \eta < 5.0$

$p_{total} > 2.5$ GeV

$p_T^{\mu_1} > 1.7$ GeV



REMARK: We're assuming no changes to the trigger or tracking performance in the upgrades of LHCb.

Particle reconstruction @ LHCb

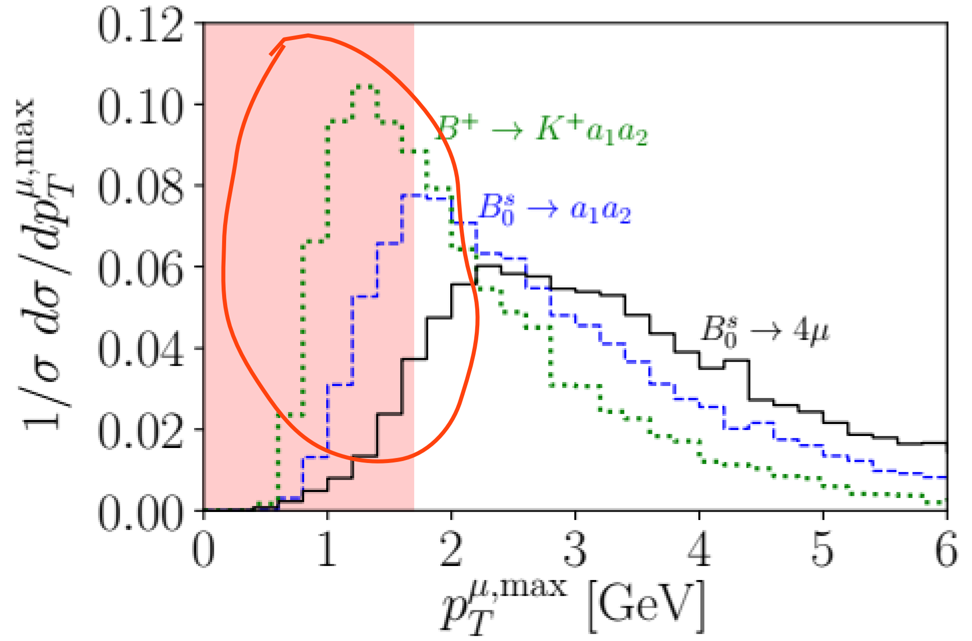
Basic cuts

$p_T > \overset{<0.4}{0.5}$ GeV

$2.5 < \eta < 5.0$

$p_{total} > 2.5$ GeV

$p_T^{\mu_1} \cancel{> 1.7}$ GeV



What I've learnt here

Expected branching fractions

$X = m_{B_s0}$ or
$m_{B+} - m_{K+}$

	$m_X \geq m_1 + m_2$		$m_X < m_1 + m_2$
	$m_2 \geq 2m_1$	$m_2 < 2m_1$	$m_X \geq 3m_1$
$B_s^0 \to 3\mu^+ 3\mu^-$	[0.02,0.03]	[0.01,0.02]	[0.02,0.03]
limit ($\times 10^{-9}$)	$[6.7, 11.6]$	$[7.9, 18.2]$	$[6.0, 11.9]$
$B^+ \to K^+ 3\mu^+ 3\mu^-$	[0.007,0.009]	[0.003,0.009]	four-body
limit ($\times 10^{-9}$)	$[5.9, 8.0]$	$[6.0, 16.6]$	four-body

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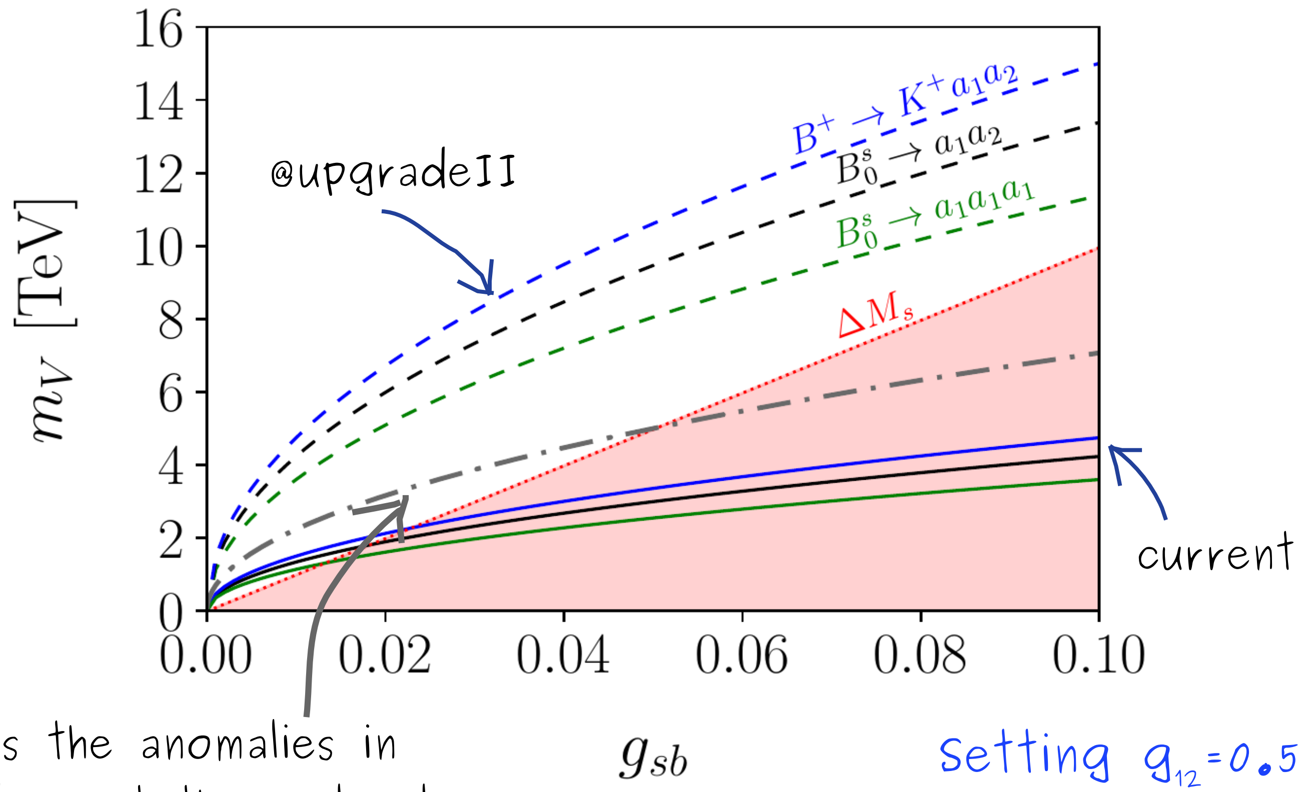
stronger

$f_{B+} = 3.7 f_{Bs}$

Further motivation to search for this final state

Maximum m_V that can be tested



@upgradeII

current

Explains the anomalies in R_K and R_{K*} at the 1σ level (1712.06572)

Setting g_{12}=0.5, $m_1(m_2)$=1.2(2.0) GeV

If a signal is observed:

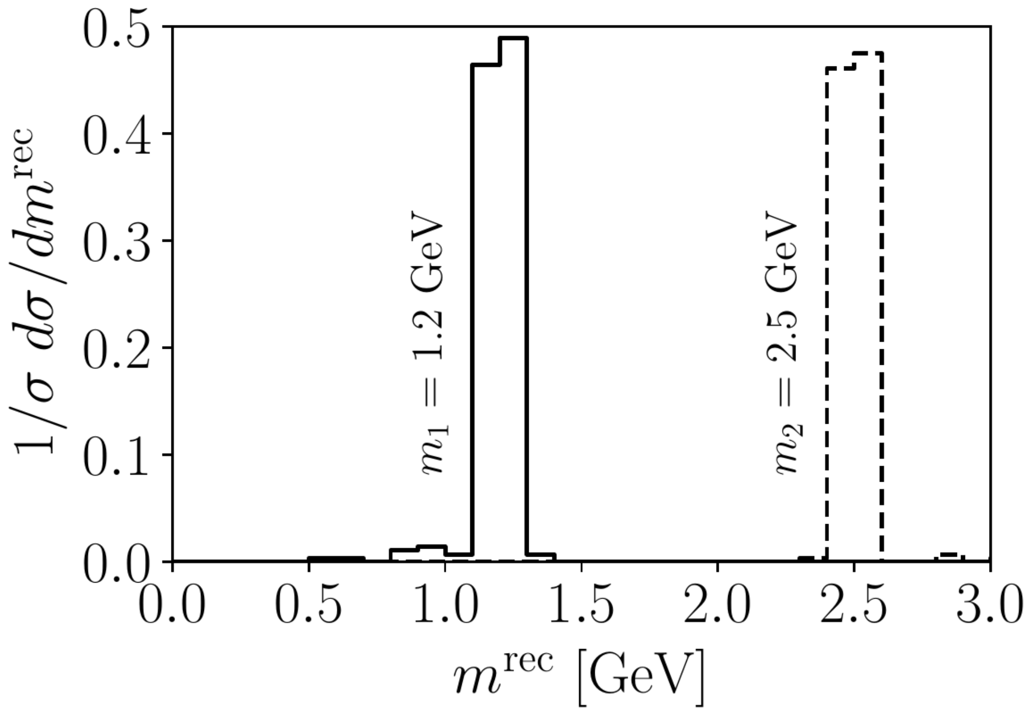
Algorithm:

($m_2 > 2m_1$)

- Minimize

$$|m_{11}^{rec} - m_{12}^{rec}| + |m_{12}^{rec} - m_{13}^{rec}|$$

- Reconstruct a_2 from the two closest a_1^{rec}



Conclusions

- Non-minimal CHMs are predictive candidates for NP; however there are no signals of NP at the LHC
- Heavy vector – light scalar couplings arise naturally
- Since V is out of reach, this scenario triggers rare B-decays:

$$6.0\; B_s^0 \to 3\mu^+3\mu^- \quad \text{and} \quad 5.9\; B^+ \to K^+3\mu^+3\mu^- \qquad \times 10^{-9}$$

$$(B^0)\ 1.6 \qquad\qquad (B_s^0 \to K^{*0})\ 18.$$

- None of these signals has been explored experimentally
- The three-body decay is a *key* signature
- Sensible probe of effective operators

Thank you very much for your attention!

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